HEDGE: HYPERSONIC REENTRY DEPLOYABLE GLIDER EXPERIMENT

SATELLITE CONSTELLATIONS AND THEIR EFFECT ON RADIO ASTRONOMY

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

As the cost of manufacturing and launching spacecraft decreases, more spacecraft are being put into space. While this might be considered a significant capability advancement since it means more investment and discoveries of new ways to use satellites, there are some direct effects on the ground resulting from the increasing number of radio signals being broadcast from above. Radio astronomy is increasingly affected in its ability to get clear signals and it is getting worse as mega-constellations are launched which promise to bring the internet from space. "Any type of radio communication and intended radio transmissions is regulated to avoid a situation where different operators–when using the same or nearby frequencies–create interference on each other's systems" (Di Vruno et al., 2023). For my research paper, I would like to take a closer look into what exactly the effects are on astronomers' ability to get radio astronomy data and whether anything is being done to ensure that it does not get worse. My main research question is: What is the effect of the increasing number of satellites on Radio Astronomy? I also plan to discuss what radio astronomers are doing about it and whether their concerns are being heard. This topic will relate to my technical project as I am a member of the communications subteam for the HEDGE: Hypersonic ReEntry Deployable Glider Experiment with Professor Goyne. As part of the communications sub-team, we are focused on getting the collected data back from space, which also introduces additional radio "noise". Additionally, I worked at Iridium Communications this past summer which operates a constellation of satellites providing space-based communication and we are using Iridium for HEDGE to transmit the data back from space. I have discussed this with my thesis advisor within the astronomy department and he is willing to put me in touch with the National Radio Astronomy Observatory (NRAO) which has its headquarters here in Charlottesville. My first step will be to gain background on what current astronomers are dealing with the new constellation and then I intend to reach out to the NRAO to ask additional specific questions. I intend to proceed with detailing the findings by using the Actor-Network theory or the ANT method. This topic is very interesting to me as it came up in many of my conversations during the Iridium Communications internship I had this summer. I have wanted to dive into more about just how bad radio signal interference has gotten and what is being done as far as mitigation.

Technical Project

Problem and Significance

The United States is quickly trying to catch up to years of advancements of other world powers such as China and Russia in hypersonic technology especially in international warfare where according to Air Force General Glen D. VanHerck, “hypersonic weapons are extremely difficult to detect and counter given the weapons' speed and maneuverability, low flight paths and unpredictable trajectories.” Hypersonic weapons as defined by the Voice of America are weapons that “fly at speeds of at least Mach 5” (or five times the speed of sound). These weapons can be used for defense and offensive capability and can provide the country that wields them a significant advantage as they are extremely hard to detect. Because of the staggering difference in the progression of hypersonic technology between the United States and other foreign countries, the question becomes *what can be done to catch up within the next decade*. CubeSats have become an emerging technology over the past few decades for their ability to deliver cutting-edge experiments into space for a reduced price by creating a standard form factor for these experiments and reducing the costs for new parts for each experiment.

For our technical project, we will be working with Professor Goyne on the Hypersonic ReEntry Deployable Glider Experiment (HEDGE). This is a CubeSat that will test new materials and their ability to re-enter the atmosphere. Our role within the project is to work on the communications subteam to ensure that the data collected from the experiment can be received on the ground.

Goals of Our Research and Design

The focus of our project is to get the CubeSat to reenter into Earth's atmosphere at hypersonic speeds, which will then allow us to collect data on how hypersonic speed conditions on reentry affect different materials. We will collect data as the CubeSat is speeding through the atmosphere and send it up to an Iridium satellite. This satellite will send the information collected back down to us on the ground for processing and analysis.

Our more specific role in this project entails working on the communications aspect of this CubeSat. We are working on data transmission through an antenna on the satellite and working to set up a successful way to recover this data using an Iridium relay satellite. We are exploring and enhancing the communication systems of the CubeSat, ensuring reliable data transmission and reception during the crucial phases of re-entry, thereby contributing to the overall understanding of material behavior and enabling more efficient data acquisition for future space exploration missions. Some of the challenges of this include the design of the circuit boards and onboard computer for data translation, placement of the antenna on the CubeSat for optimal signal directing, data collection on the ground, and external factors such as heat that could affect the mission.

Methods

Our initial approach involves the precise calculation of the required data transmission rate that aligns with the functional objectives of the communication team, collecting 4 measurements per second. The first step of the process consists of reviewing the previous class's determination. It was found that 4 thermocouples and 4 pressure transducers on the spacecraft would provide readings, each measurement being 2 bytes. After calculations, they got a total of 53 kbytes transmitted over a period of 16 days. We can use this information to start our process of proving that all requirements are met.

The next approach we will take is to ensure 100% transmission coverage. However, there are a few issues that we will need to address first. The base design of the CubeSat currently has the antenna facing behind the CubeSat. The Iridium Communications Satellite that we will be using though has satellites in orbit that are facing straight down as they are optimized for complete coverage of the surface of the Earth (Maine et al., 1995, pg. 484). The beams on the satellites spread out as they get closer to the surface which means that the closer to the satellite, the less area the beams cover. When the cubesat is first launched into space, it will be in a fairly circular orbit resulting in the antenna facing behind the satellite. An image of one example Iridium satellite and HEDGE after initial deployment can be seen in Figure 1. While the antenna being used is fairly omnidirectional, which means that it should be able to send a signal in any direction, the fins of HEDGE are made out of Inconel which means testing needs to be completed to see if the signal will be able to penetrate through it. The second main challenge is to ensure that HEGE will be able to stay in contact with Iridium Satellites while it is re-entering the atmosphere. Some

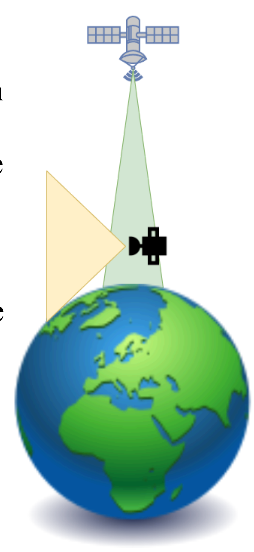

Figure 1: (Draw.io)

challenges associated with this include thermal heating of the antenna and transceiver and also keeping line of sight with the Iridium Satellites. Figure 2 shows the difficulty with keeping in contact with the relay satellites as their beams are cone-shaped meaning that they cover less area closer to the satellites and there are larger gaps in the network as discussed above.

To enable a functioning communication system, the Iridium 9603 Transceiver needs to be linked with both the motherboard and an antenna. During the prototype phase, we will utilize the RockBLOCK 9603, which combines the Iridium 9603 transceiver and a patch antenna in one unit. The RockBLOCK 9603 will then establish a connection with the Raspberry Pi via a 10-pin Molex-style cable.

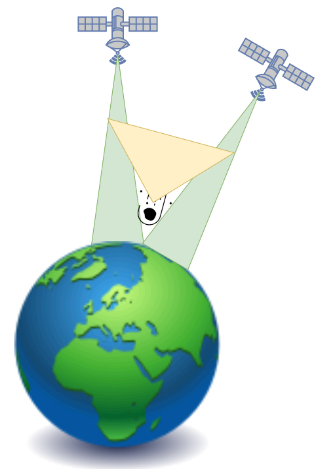
Figure 2: (Draw.io)

This connection to the Raspberry Pi facilitates the transceiver's ability to receive commands and access power. For the actual in-flight mission, we will affix the Taoglas IP.1621.25.4.A.02 patch antenna to a PCB board that incorporates a built-in ground plane. This will be accompanied by a U.fl cable that connects to the transceiver. The Iridium 9603 Transceiver is equipped with a Samtec low-profile header connector, which is designed to be attached to a Samtec header female socket. This configuration allows for the transceiver to be soldered onto a PCB, creating a connection with the onboard computer for the in-flight mission.

Available Resources

Some resources available for the capstone include Professor Goyne and Professor McPherson. The CubeSat design lab is also available and there are parts purchased last year including an Iridium 9603 and the Taoglas Patch Antenna. Also, the team is fortunate to have a few electrical engineering students working with the class on the design of the boards and some basic software that will interface with the Iridium transceiver. Further components will be purchased once funding for the project is finalized and the team is cleared to proceed with integration.

Objectives for Spring Semester

Following the TIM, our Spring semester objectives focus sharply on the testing, assembly, and integration of the communications subsystem. The first primary focus on integration is with the Software and Avionics team, as we need to be able to test our transceiver for two conditions: the ability to connect with and transmit through the atmosphere to an Iridium satellite, and the ability to ensure reliable communications in a simulation of re-entry conditions. A vital part of this integration process is programming the OBC to automatically encode and send both our spacecraft vitals and sensor data. Additionally, we must ensure our OBC and communications protocols have layered redundancy through the implementation of error-correcting memory or error-correcting code. Successful tests of the above will demonstrate the ability to reliably communicate with HEDGE via the Iridium network. Additionally, we need to work alongside the Power, Thermal, and Environment team for the integration and placement of communication components and mounting. The antenna placement is of high importance here, as it needs to be able to resist the high temperatures while maintaining strong omnidirectional broadcast characteristics.

STS Topic

The topic that I will be looking into for my STS Project is looking into the effects of the growing number of satellites on astronomers' ability to get radio astronomy data and whether anything is being done to ensure that it does not get worse. Constellations such as Starlink, Kuiper, OneWeb, and Telesat have started or will soon deploy many satellites into orbit around Earth (Di Vruno & Tornatore, 2023). Constellations have been under pressure to work toward mitigating the effect that they have on visible astronomy, but radio astronomy requires a similar level of scrutiny, which may not be occurring. Iridium, which is another satellite constellation that has been around for several decades, has worked through most of its issues with radio astronomy, but only has 66 satellites in the constellation, compared to the thousands that the new constellations will have (Deshpande & Lewis, 2019). It is not just constellations either, over time, the number of active satellites in orbit continues to rise, and that will impact radio astronomers as the airwaves get more congested.

Ground-based astronomy is an important aspect of science that is exceedingly difficult to replicate in space. While image and radio signal quality might be significantly better for spacecraft or telescopes in space, the size of a telescope is significantly limited by what is able to be launched. On the ground, this restriction does not exist, which means larger telescopes can be built that detect weaker signals. Global communication also continues to be an important part of daily life. COVID-19 showed that having a reliable connection to the internet is a necessity in the modern world. To provide access to those who might not have access to high-speed internet, new constellations are currently being developed with goals to incorporate tens of thousands of satellites when completed (Di Vruno et al., 2023). Global spectrum management is becoming more and more important. Unlike some resources, the spectrum is finite, meaning there are only so many frequencies that can be used for different applications like communication and radio astronomy. Over time the frequencies are getting closer to one another which means that it is more likely for interference to occur (Zheleva et al., 2023). It is especially difficult for astronomers when a spacecraft is transmitting at a frequency that could also be from an extra-terrestrial source, making it almost impossible for astronomers to tell whether the signal is man-made or not.

There are several groups that are either directly or indirectly involved or have some say in this issue. Radio Astronomers are the ones who are being directly impacted by the rise of spacecraft numbers. Satellite companies are making money by sending satellites into space and are directly involved with the availability and use of spectrum, but are generally the ones causing the interference. Policymakers dictate who and who can't use parts of the spectrum and where they can use it. Consumers are the ones who use the services provided by the satellites. Other groups that might have a say in the issue include those that are building the satellites or satellite manufacturers, the companies launching the spacecraft, and the larger scientific community. It's important to collect the viewpoints from each of the differing perspectives as the satellite companies and the radio astronomers might point the finger at each other for who should be responsible for the issues created. The satellite companies might also downplay the impact the satellites have on radio astronomy. An interesting viewpoint will be to look at the opinion of the policymakers and regulating agencies since they should maintain an equitable stance in the matter of allocation and oversight of the spectrum.

To get a good understanding of the issues and viewpoints, a mix of historical references, public policy, and communications and media will be used. Using a mix of these differing methods will give a complete picture of the different stakeholders and their perspectives on the effect of the increasing number of satellites on ground-based radio astronomy. I plan on using the fact that UVA is so close to the headquarters of the National Radio Astronomy Observatory to my advantage by reaching out and talking to them about their opinions and knowledge related to the issue. To accomplish this, Actor-Network Theory or the ANT framework will be leveraged. The ANT framework postulates that there are specific and changing relationships between the parties involved that make up every issue.

Much of the research will happen in the November and December 2023 timeframe, but reaching out to stakeholders will occur in late October 2023. Organization of the information learned will occur in December 2023 and then in January 2024, writing of the thesis will begin and will be complete by March 2024. April 2024 will be used for final editing and review by neutral reviewers.

Primary Sources

There are four sources that I have found so far that I'd like to take a closer look into. *Radio Dynamic Zones: Motivations, Challenges, and Opportunities to Catalyze Spectrum Coexistence* gives a good summary of how frequencies have developed over time. The paper explains the current methods of regulating the frequencies and why those are out of date. The second source that I have found is *Iridium Satellite Signals: A Case Study In Interference Characterization And Mitigation For Radio Astronomy Observations* which highlights some of the issues that have already been experienced after years of a constellation being operated and some of the things that have been done to try and mitigate the issues. It is important to have some context for some of the solutions that have been implemented and if they can be used on a larger scale with more satellites. The third source is *Unintended electromagnetic radiation from*

Starlink satellites detected with LOFAR between 110 and 188 MHz which gives a good background of the history of radio astronomy and then discusses that some satellites are giving off signals that they shouldn't be emitting. Since they're not supposed to be emitting these signals it's harder for astronomers to remove this noise from the data they're getting. The final source that I have is the National Radio Astronomy Observatory in Charlottesville, VA. A professor passed contact information to me for someone at the observatory to reach out to and ask some questions about the topic. They will be instrumental in being able to ask the tough questions that are not necessarily addressed in the research papers and really understand the opinion of radio astronomers about these constellations as it is difficult to gain an understanding from papers alone.

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